The DSN Array Development Program

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May 23, 2002

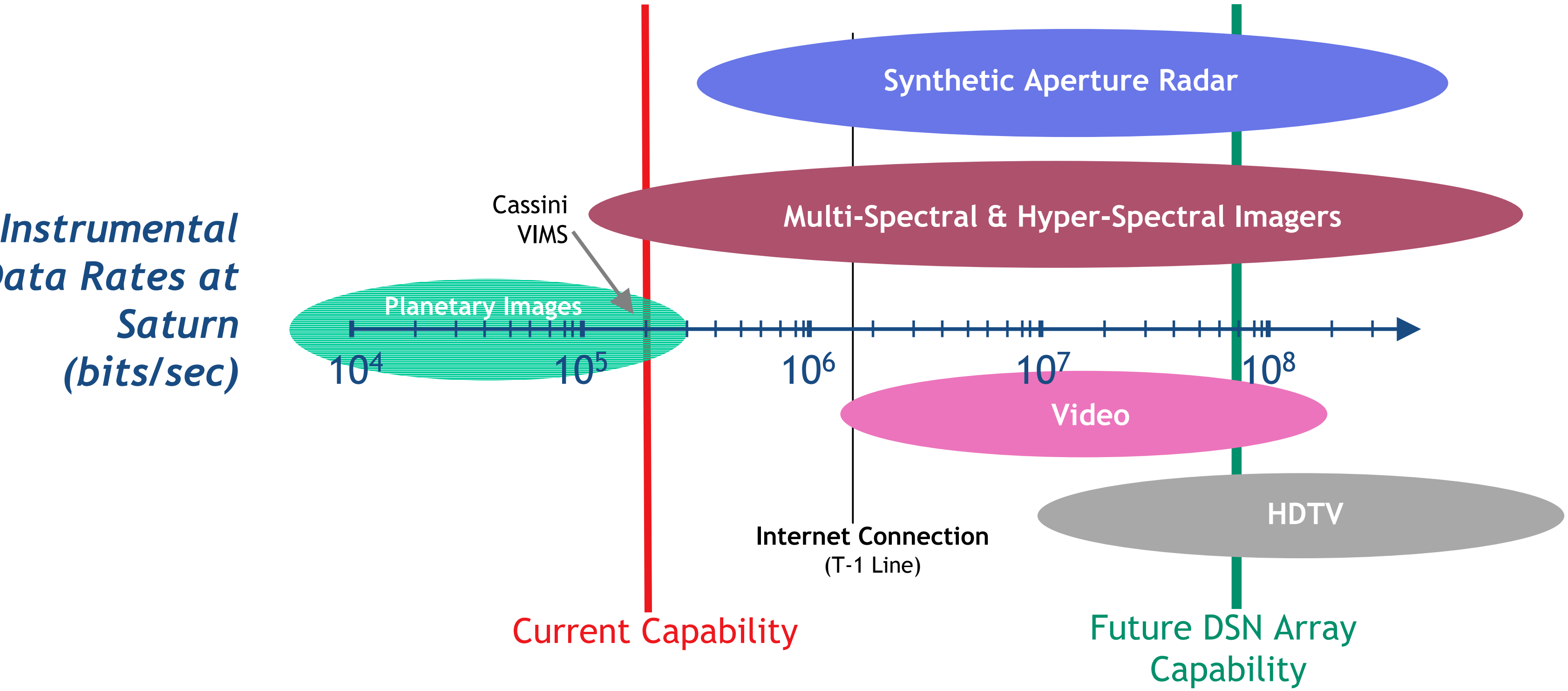
- Why Arrays for DSN?
- Other Arrays - Current and Future
- Basic Array Signal Processing
- Array Technology
  - Overview, System Design
  - Antennas, Feeds
  - Low Noise Receivers
- JPL Plan
- Caltech Plan

Why Arrays for Space Communications?

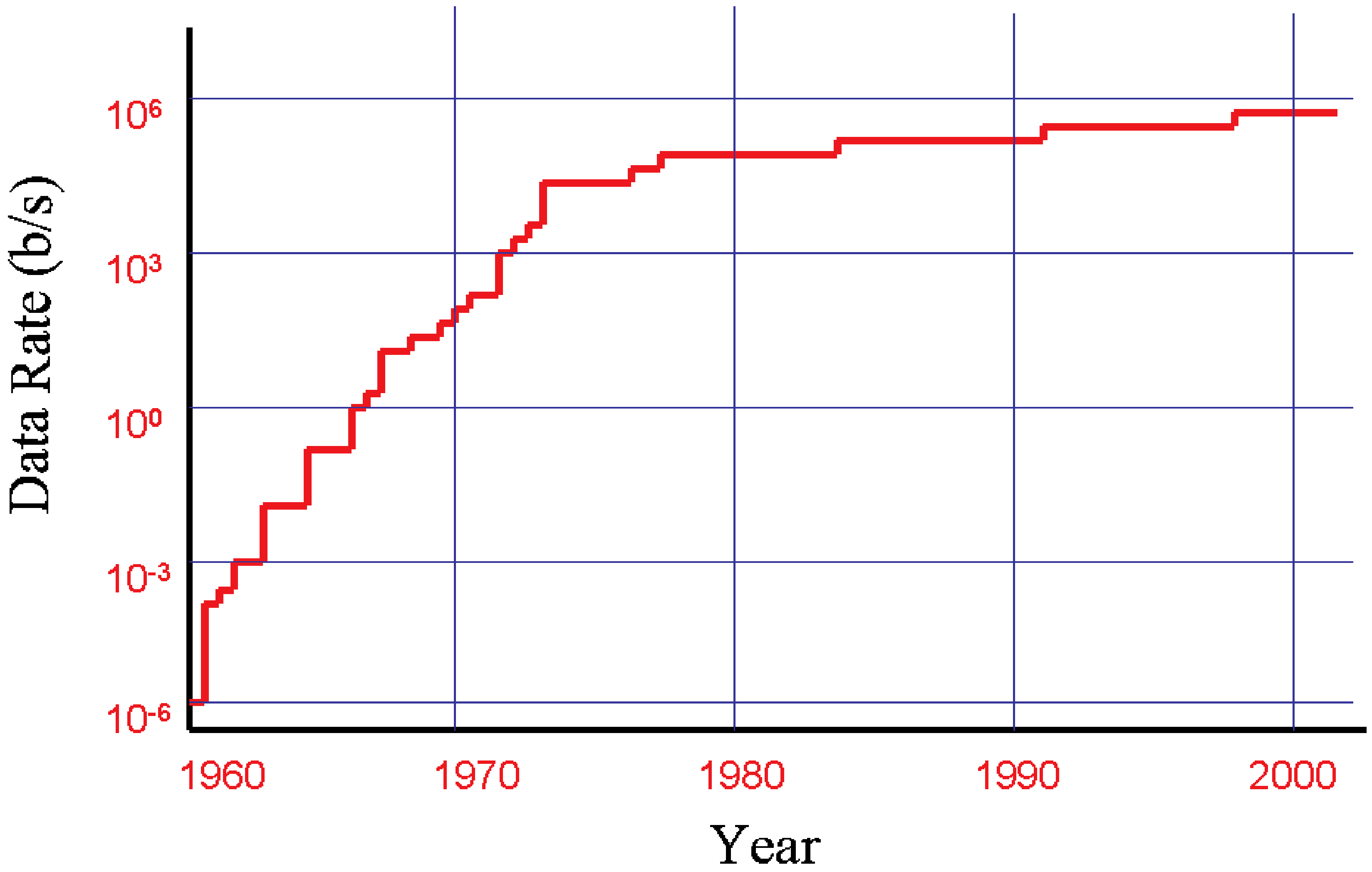
- **Much Lower Cost per Unit Area** - Costs of large antennas are proportional to $D^{2.7}$ where D is the diameter. Collecting area is proportional to D^2; thus to increase collecting area it is less expensive to have large numbers of small antennas.
- **Multibeaming** - Arrays can have many simultaneous beams with full collecting area within the primary beam of the small antenna. Array can image a region of sky whereas this is difficult to do with single antennas.
- **Partitioning** - Arrays can be partitioned into sub-arrays to serve many diverse missions with “Just Enough” capability on each.
- **Soft-Failure** – Failure of a few percent of the elements has very little effect on the total array.
- **Navigational Advantage** – By distributing array elements high angular resolution is achieved.
- **Available Technology** – Low cost small antennas, microwave integrated circuits, fiber-optic signal transmission, and fast digitcal IC’s..
- **Spacecraft Equipment Heritage** – No change required.

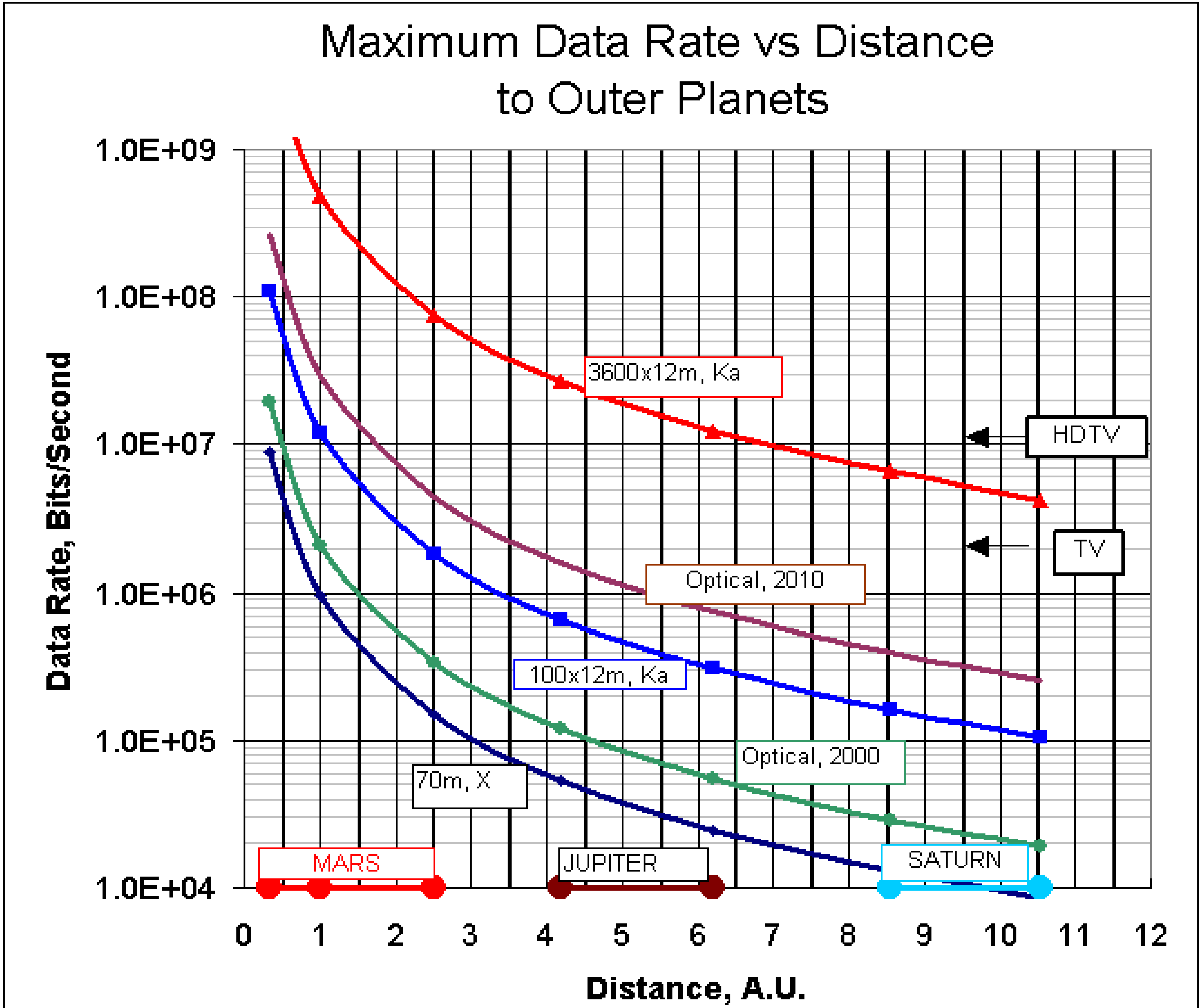
Increased Area Greatly Increase Data Rates to Distant Spacecraft

- Future NASA missions are severely limited by the current DSN data rate.
- A Square Kilometer of DSN-Array would:
  - ✓Provide factor of 100-500 increase in data rates for missions to outer planets
  - ✓Allow much smaller and less expensive spacecraft with current data rates
  - ✓Provide much greater navigational information than existing antennas
  - ✓Allow simultaneous communication to several spacecraft



Deep Space Communications Capability





Maximum Data Rate vs Distance to Outer Planets
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
Data Rate, Bits/Second
0
1
2
3
4
5
6
7
8
9
10
11
12
Distance, A.U.
3600x12m, Ka
HDTV
TV
Optical, 2010
100x12m, Ka
Optical, 2000
70m, X
MARS
JUPITER
SATURN

Comparison of Existing Large Antennas and Future Arrays

Antenna	Elements	Effective Area	Upper Frequency	Tsys	A/Tsys	Year Finished
DSN 70m	1 x 70 m	2,607	8 GHz	18	145	1965
GBT	1 x 100 m	5,700	100 GHz	20	285	2000
VLA	27 x 25 m	8,978	43 GHz	32	280	1982
Arecibo	1 x 305 m	23,750	8 GHz	25	950	1970
ALMA	64 x 12 m	4,608	800 GHz	50	92	2011
ATA	350 x 6 m	6,703	11 GHz	35	192	2005
DSN Prototype	100 x 12m	7,200	38 GHz	20@8GHz 40@32GHz	360 180	2007
DSN Goal	3600 x 12m	259,200	38 GHz	18@8GHz 36@32GHz	14,400 7,200	2012
SKA	4550 x 12m	327,600	22 GHz	18	20,000	2016

What is the SKA?

- An international project to design a very large area array for radio astronomy in the cm wavelength range.
- The web site, http://www.skatelescope.com, contains science justification and links to activities in several countries
- US approach is a large array (≈4,500) of small (≈12m) antennas , organized into a 1000km diameter spiral of ≈100 close packed stations

Key Specifications

- Aeff/Tsys > 20,000 m^2/K

(1 square km with Tsys=50K)

- Frequency, 0.15 –40 GHz
- Resolution 35 nano-radians

(5km beam at 1 A.U. at 20GHz)

SKA Consortium Members

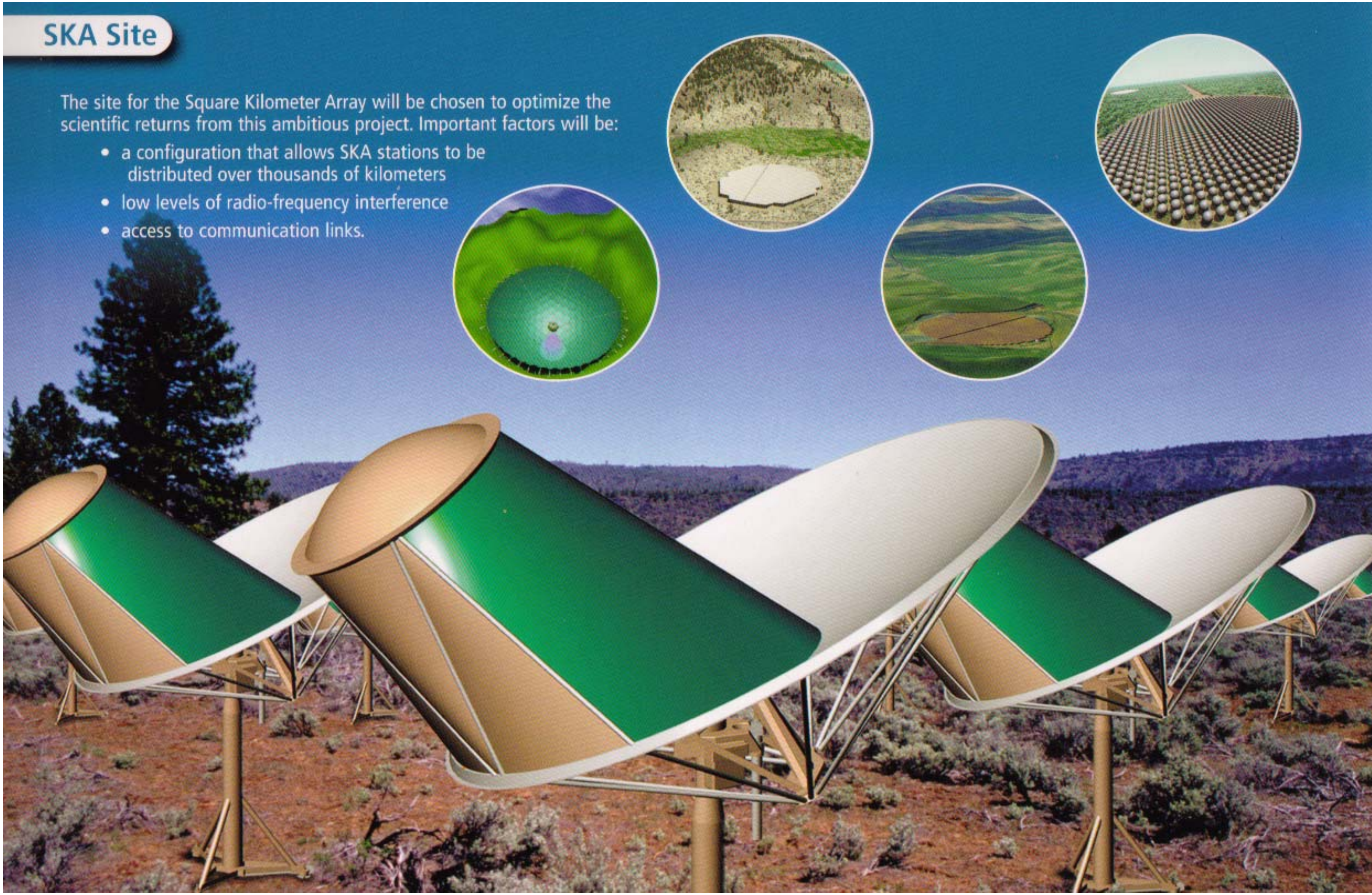
The international consortium planning the Square Kilometer Array at present include

- **USA**
  The US SKA consortium: **www.usska.org**
  - **California Institute of Technology,** including the Jet Propulsion Laboratory
  - **Cornell University,** including the National Astronomy and Ionosphere Center
  - **Harvard-Smithsonian Center for Astrophysics,** including the Smithsonian Astrophysical Observatory and Harvard College Observatory
  - **Massachusetts Institute of Technology**, including Haystack Observatory
  - **National Radio Astronomy Observatory**
  - **Naval Research Laboratory**
  - **Ohio State University**
  - **SETI Institute**
  - **University of California, Berkeley**
  - **University of Minnesota**

The SKA is the first project in the field of radio astronomy that has been "born global", growing out of discussions within URSI (the International Union of Radio Science) and the IAU (International Astronomical Union). The scientific case for the SKA project has been developed by the URSI Large Telescope Working Group. Organizations in ten countries have committed themselves to sharing research and development for the instrument.

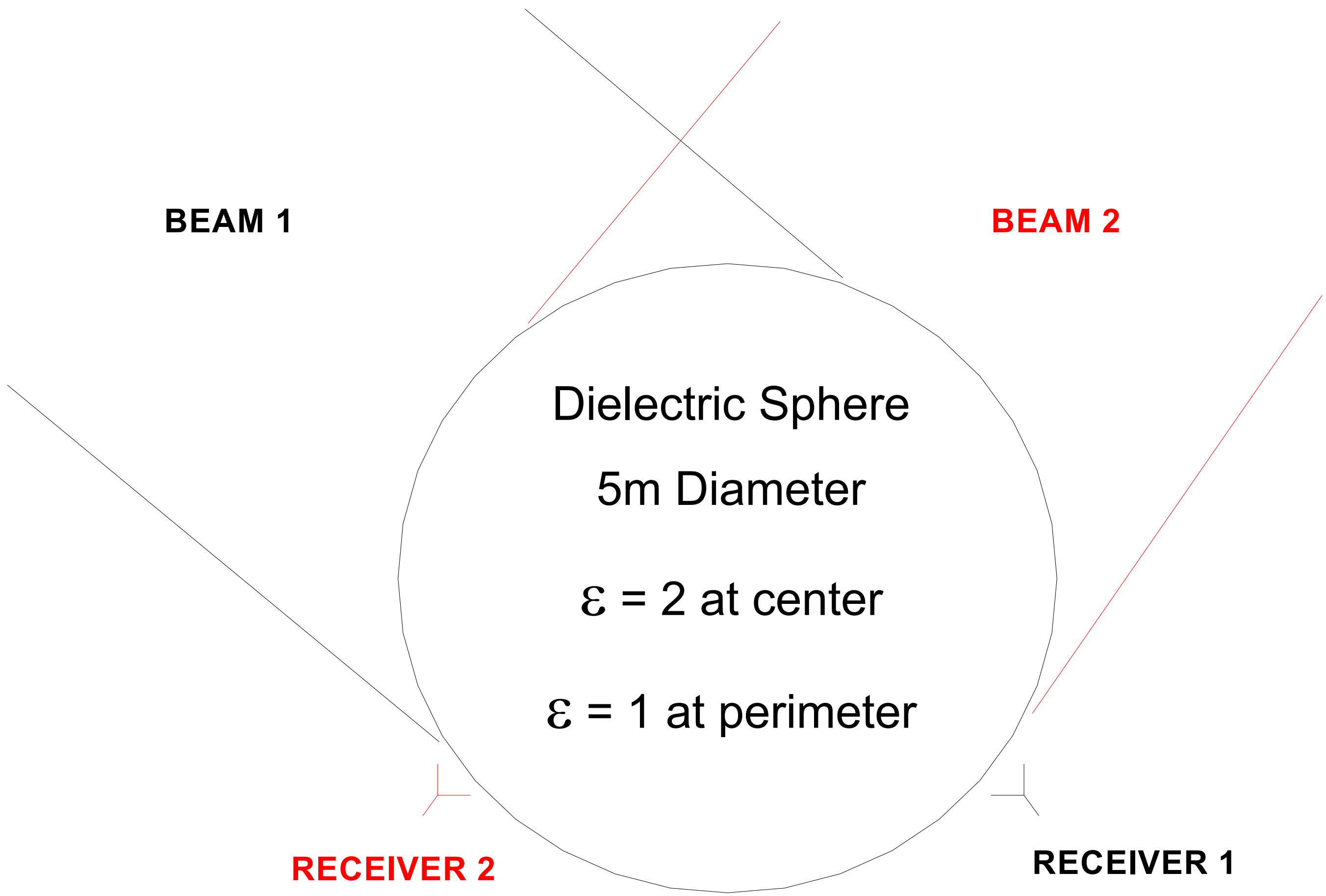
- **Australia**
  - Australia Telescope National Facility, CSIRO
  - Swinburne University of Technology
  - University of Sydney
- **Canada**
  - Herzberg Institute of Astrophysics
  - University of Calgary
- **China**
  - Beijing Astronomical Observatory
- **Europe**
  The European SKA consortium:
  - Istituto di Radioastronomía, Bologna
  - Joint Institute for VLBI in Europe
  - Max-Planck-Institut für Radioastronomie
  - Netherlands Foundation for Research in Astronomy
  - Onsala Space Observatory
  - Torun Centre for Astronomy
  - University of Manchester, Jodrell Bank Observatory
- **India**
  The Indian SKA consortium:
  - National Centre for Radio Astrophysics, TIFR
  - Raman Research Institute

SKA Antenna Concepts



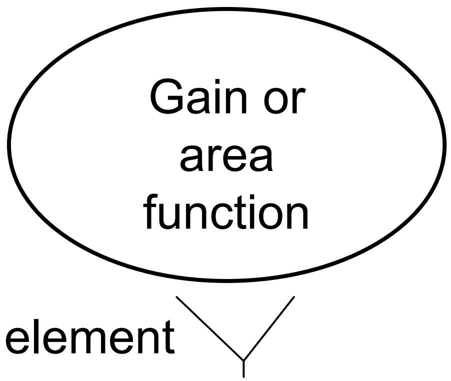
Luneburg Lens Array Antenna Element

Dielectric sphere has 360^{O} field of view



Arrays of Fixed Antennas

(Such as LOFAR or Dutch Approach to SKA)



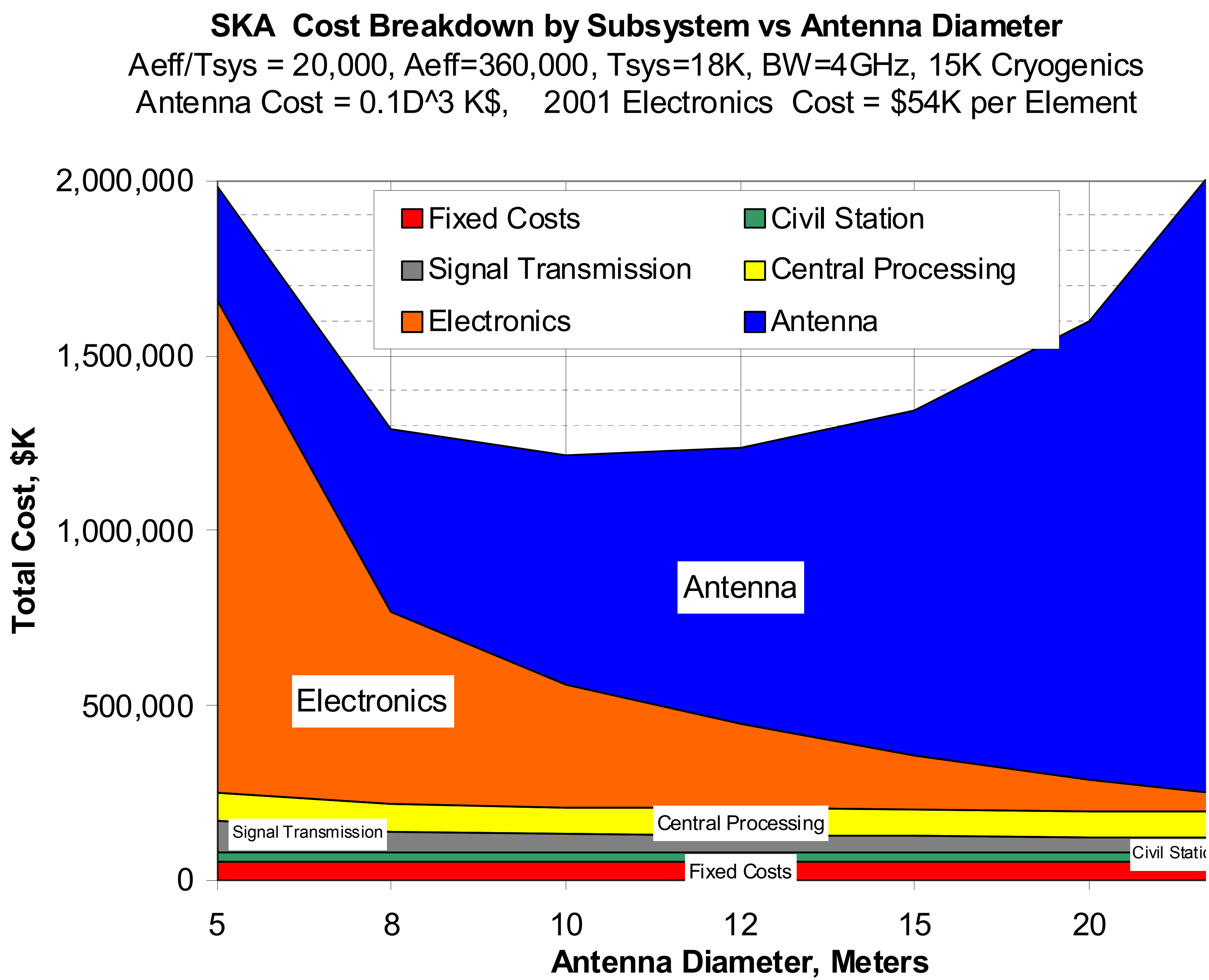
Array element

- The array can simultaneously beam form as many beams as are affordable all over the sky.
- Many observers can use the array at the same time, but the required number of elements becomes impractical at wavelengths < 30cm.

An antenna which has all sky field-of-view has an effective area of $\lambda^2 / 2\Pi$

Wavelength	**Element Effective Area, m^2**	**Number of elements for total area of $1km^2$**
21cm, 1.4 GHz	.007	142E6
1m, 300 MHz	.16	6E6
10m, 30 MHz	16	62,800

Each element must have an antenna, phase shifter, and a low loss path to a low noise amplifier



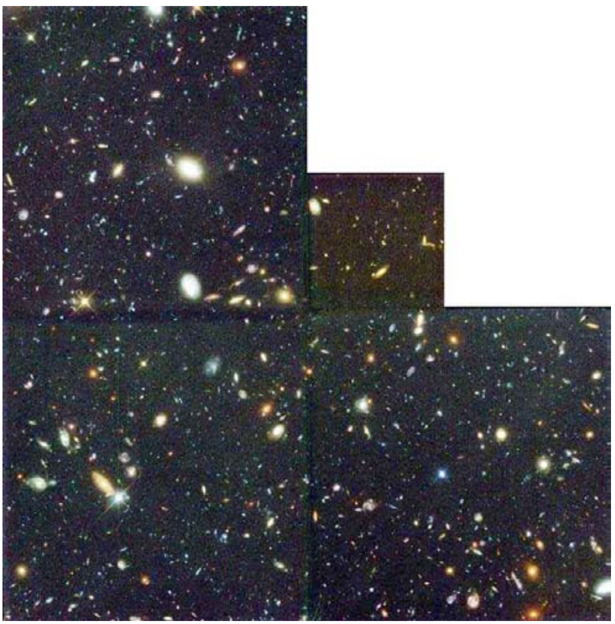
SKA Cost Breakdown by Subsystem vs Antenna Diameter
Aeff/Tsys = 20,000, Aeff=360,000, Tsys=18K, BW=4GHz, 15K Cryogenics
Antenna Cost = 0.1D^3 K$, 2001 Electronics Cost = $54K per Element
Fixed Costs
Civil Station
Signal Transmission
Central Processing
Electronics
Antenna
2,000,000
1,500,000
1,000,000
500,000
0
Total Cost, $K
Antenna
Electronics
Central Processing
Signal Transmission
Civil Static
Fixed Costs
5
8
10
12
15
20
Antenna Diameter, Meters

All Arrays are Not Large!

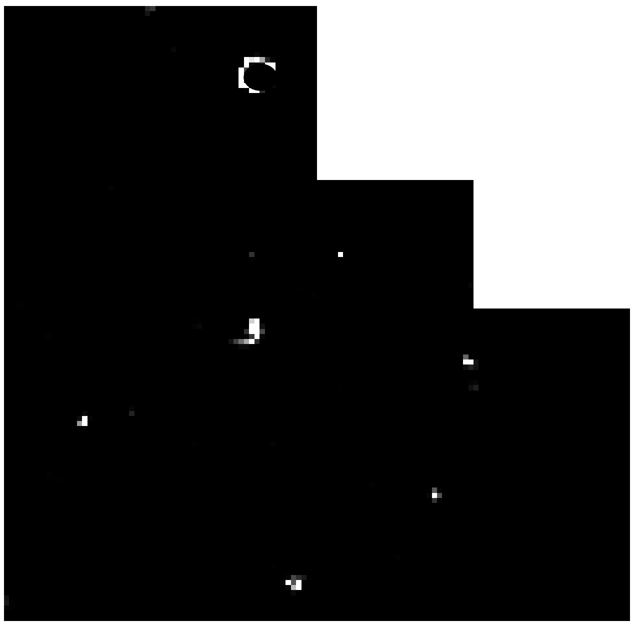
SquareCmArray – Eight Elements at 3mm Wavelength

Why do Astronomers want the SKA?

Hubble Deep Field

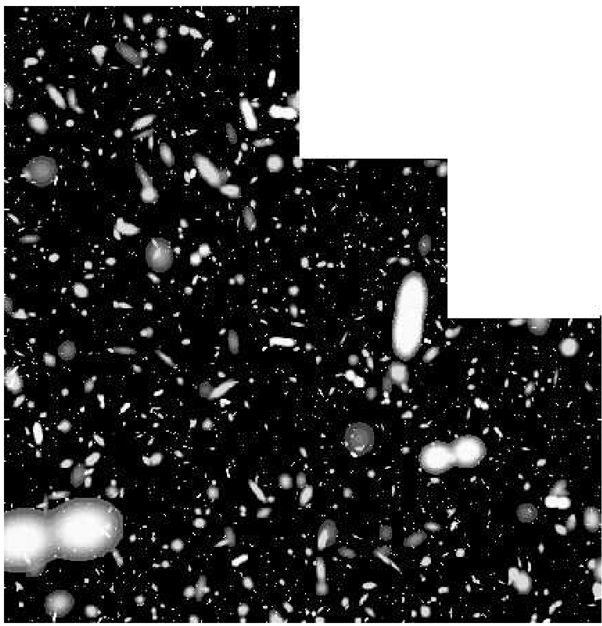


VLA



50 hours at 8.7 GHz gives
6 sources at >12 ?Jy

Simulated SKA

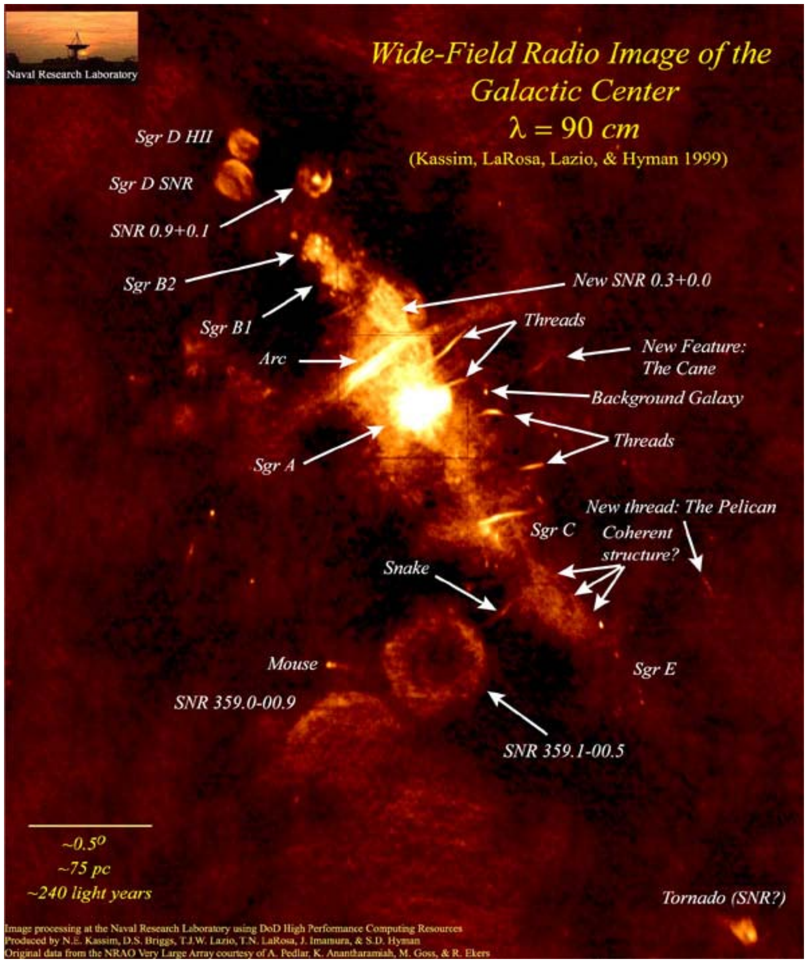


1 ? Jy sensitivity
at 1.4 GHz
(and this is just a tiny piece
of full field of view)

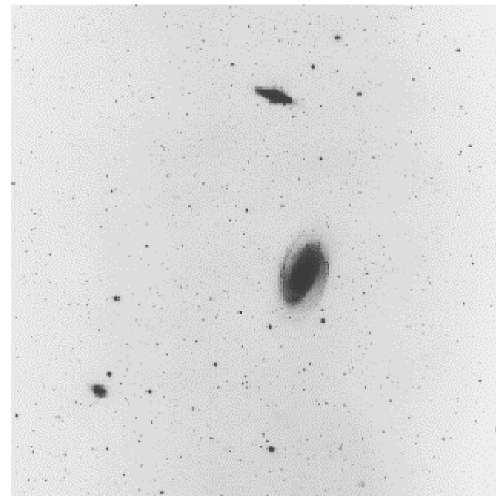
images courtesy R. Ekers

Sample Radio Astronomy Images from the VLA

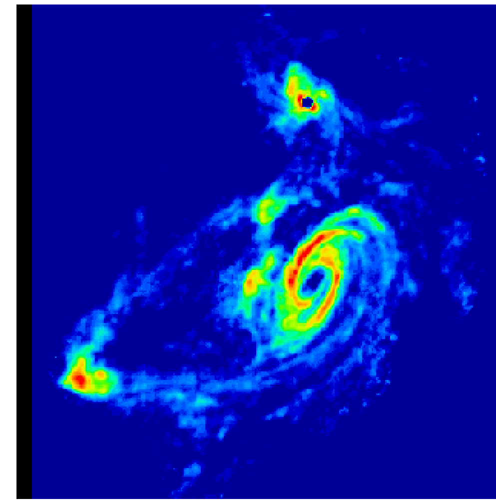
Center of Our Galaxy



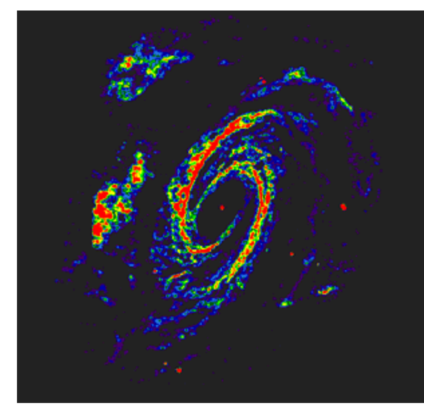
M81 Cluster of Galaxies



Optical Image



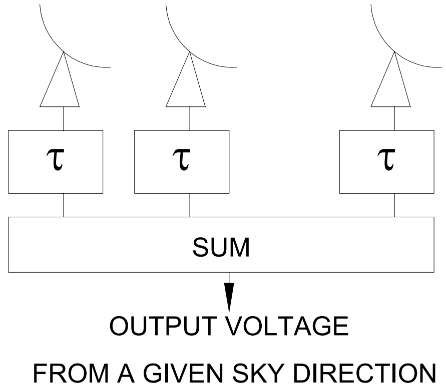
1.4 GHz H-Line Image



.33 GHz Radio Image

Two Basic Methods of Array Signal Processing

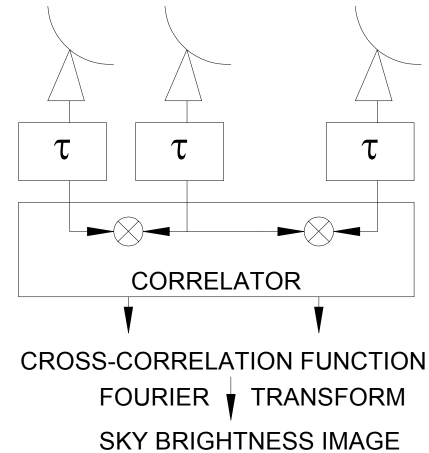
Beam Forming Array



$$X_{tot}(t) = \sum_k W_k X_k(t - \tau)$$

- Output voltage is a weighted sum of delayed input signals. The signals coherently add in a direction determined by the delays.
- Multiple beam formers can be used to simultaneously receive signals from different directions within the primary beam of each antenna.
- Output voltage as a function of time, not average power, is usually needed for communication.

Imaging Array

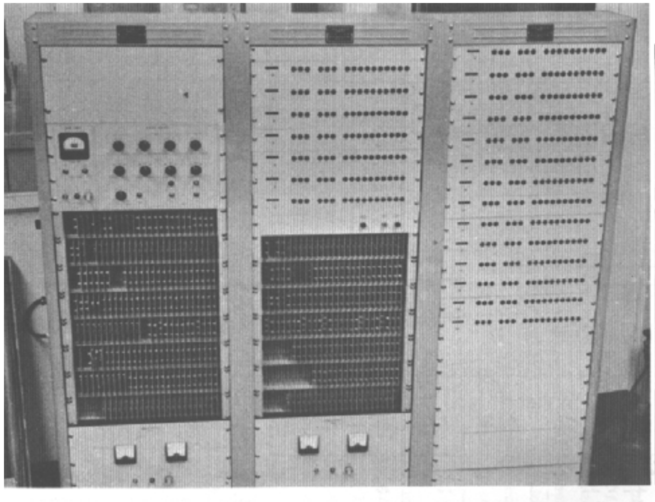


$$C(j, k, \tau) = \sum_t X_j(t + \tau) X_k(t)$$

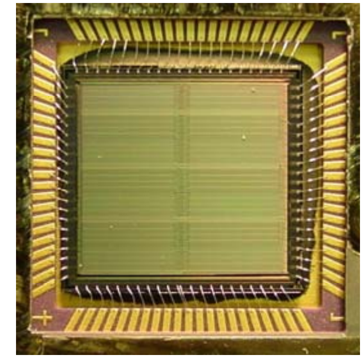
- Correlation function is a sum of products of the signals from two antennas. It is a function of spacing and time delay between two antennas.
- The 2-D Fourier Transform of the correlation function is the sky brightness or image. A transform in a 3rd dimension gives the frequency spectrum.

- In addition to the above fundamental steps signal processing involves amplification, frequency conversion, analog to digital conversion, and photonic data transmission.

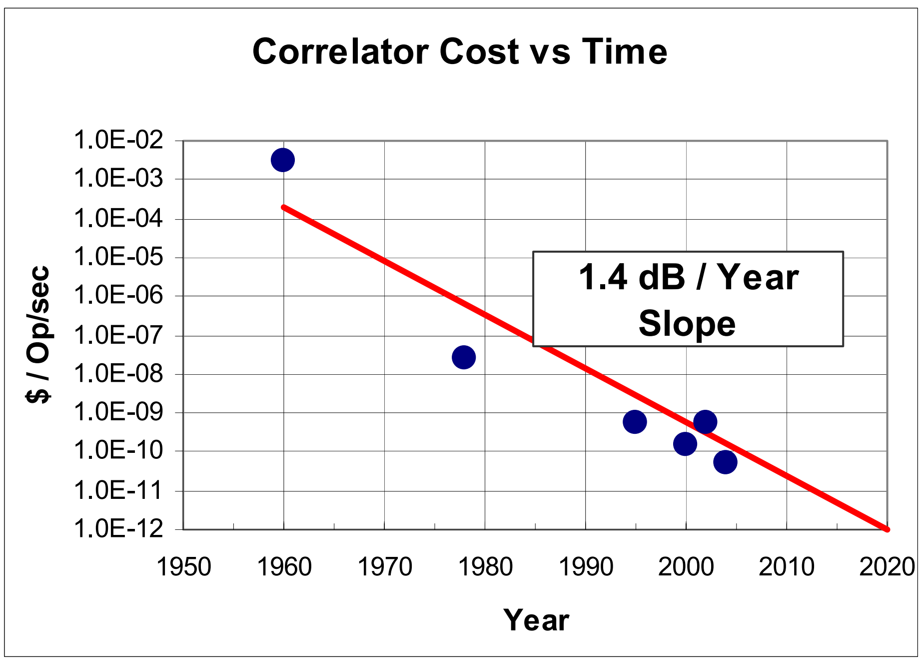
The Development of Correlators in Radio Astronomy



1960 – First Radio Astronomy Digital Correlator, 21 Lags, 300kHz Clock, $19,000



1995 – GBT Spectrometer Chip, 1024 Lags, 125 MHz Clock, $200



2005 – Proposed SKA Chip, 100 x 100 x 1 lag, 400 MHz Clock, $500

Comparison of Array Requirements for Space Communications and Radio Astronomy

Parameter	Communication	Radio Astronomy
Frequency	8 and 32 GHz	.5 to 20 GHz
Array Configuration	Any but lower cost if closely packed	Sparse for better image sharpness
Element Size	Minimum cost probably in the 3.5 to 10 meter range	May be slightly larger because of more complex receivers
Data Processing	Digital beam forming of< 10 beams	Correlation processing of full image; > 10,000 beams
Bandwidth	<10 MHz	1000 MHz

A Long-Range Plan for the DSN

JPL/Caltech 3 x 6m Interferometer - 2003 to 2005

• Provides an early, inexpensive (< $1M) test of breadboard components of the system.

• Develops a JPL/Caltech team for array technology development

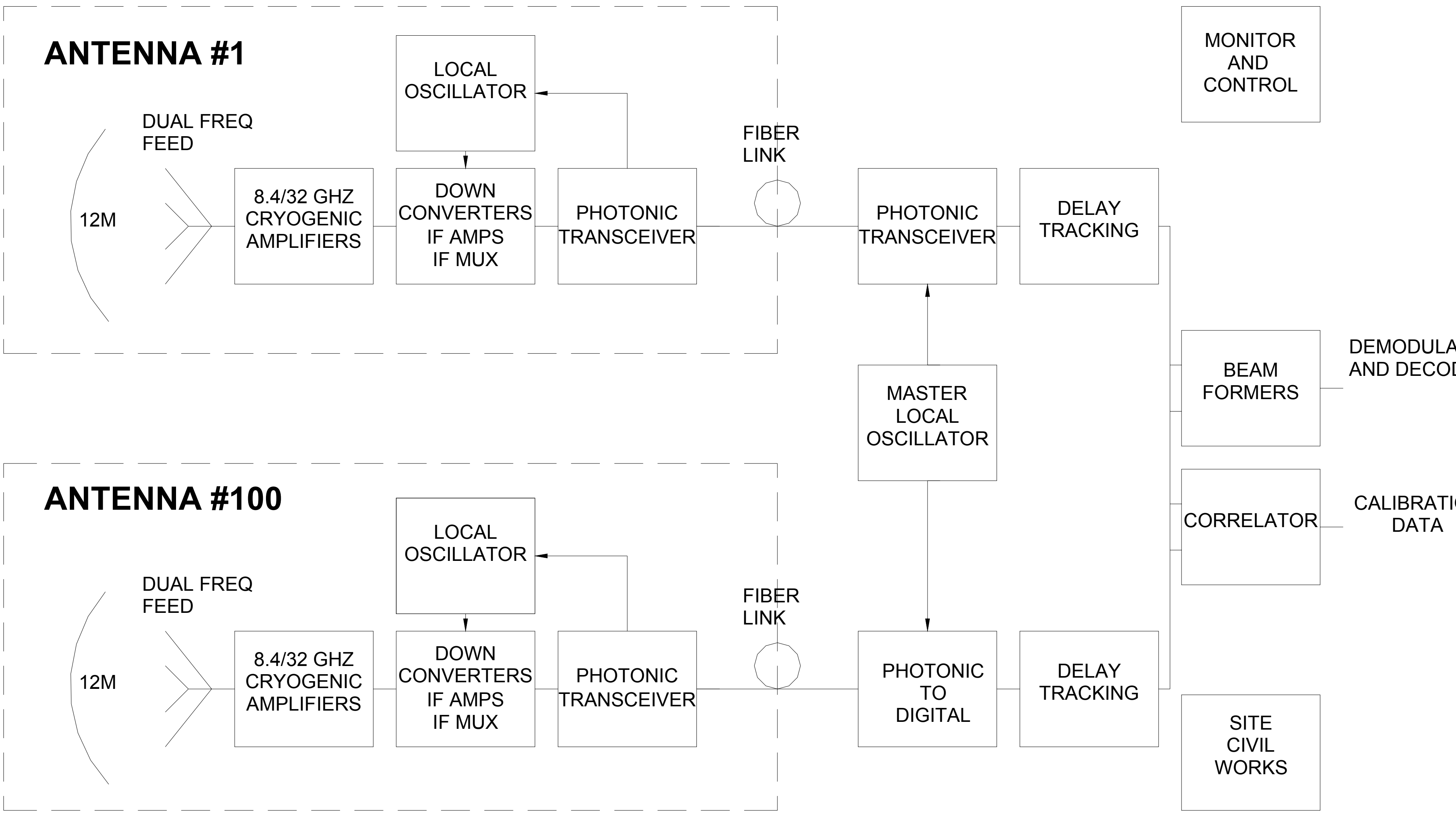
DSN Prototype 100 x 12m Array – 2003 to 2008

• Provides a solid test and demonstration of performance, cost, and operational aspects of a large array

DSN Operational Large Array – 2007 to 2015

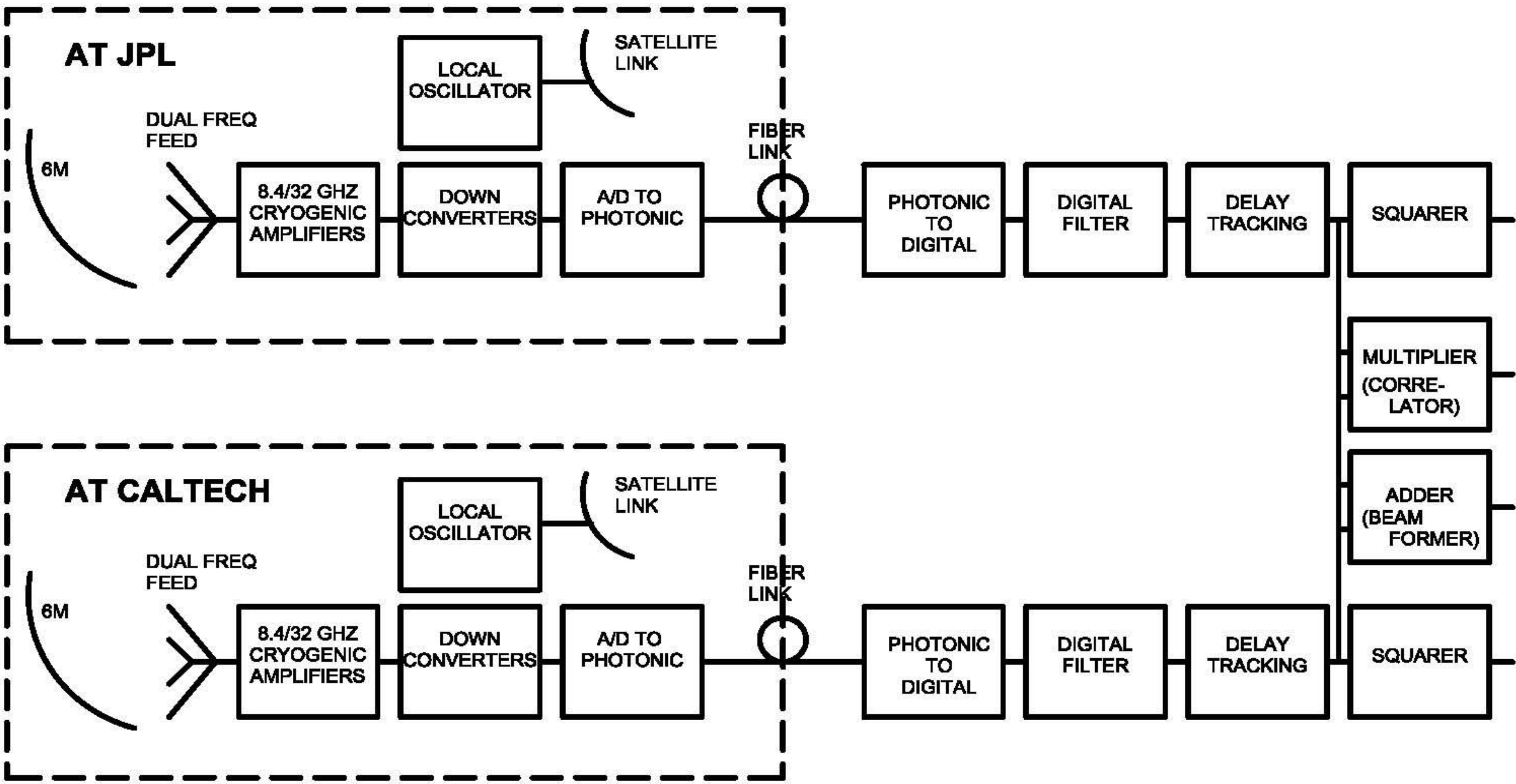
• Provides NASA with a 100X improvement in communications infrastructure to support space exploration in the 2015 – 2040 era.

PROTOTYPE ARRAY BLOCK DIAGRAM



JPL to Caltech Interferometer

- Capable of detecting both spacecraft communications and many radio astronomy sources
- Serves as an easily accessible test bed for prototype DSN and SKA equipment
- An educational instrument for thesis and research projects



Array Technology Overview

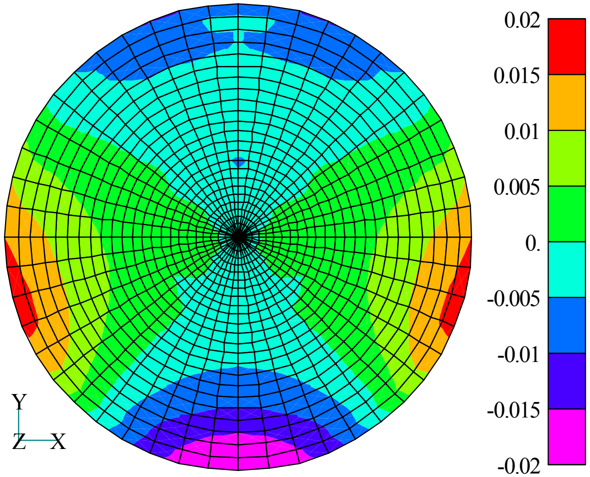
Item	Approach	Key Issues	Challange
System Design	Experience, Breadboard, Prototype	Configuration, Calibrat., Dynamic Range	Both radio astronomy & DSN
Antennas	Aluminum Hydroform	Accuracy, Cost	>12m, Lower Cost
Feed	DSN – 8/32 GHz SKA – Log periodic	Efficiency, Noise Pickup	Cryogenic Feed Window
Low-Noise Amplifiers	0.1um InP HEMT MMIC	Low Noise	Low Noise at Higher Temp
Cryocoolers	Gifford-McMann 15K Or Pulse Tube	Maintenance Cost or Development Time	No Cryo Moving Parts
Local Oscillator, Timing	Round-trip Fibers and Round-trip Satellite	Phase Stability	Commercial Satellite Link
Data Transmission	Photonic Fibers	Installation Costs for Long Distance	40 GB/s
Element Signal Processing	RF MMIC Modules, A/D Converters, Filters	Cost, RFI, Flexibility	8 GHz Bandwidth
Combinatorial Signal Processing	Digital Beam Formers, Correlators	Connections, Bandwidth	VLSI, Growth Path
Monitor and Control	Standard Modules, Serial Data Transmission	Convenient and Robust Software	Operation over Internet

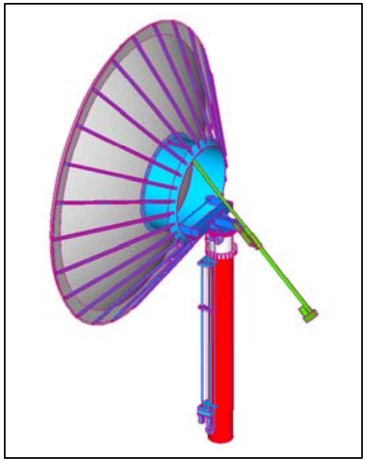
Hydroformed Aluminum Antennas

Hydroforming is a process of using a fluid or gas at very high pressure to force aluminum sheet to conform to a mold. The result is a stiff, accurate, and low cost reflector.

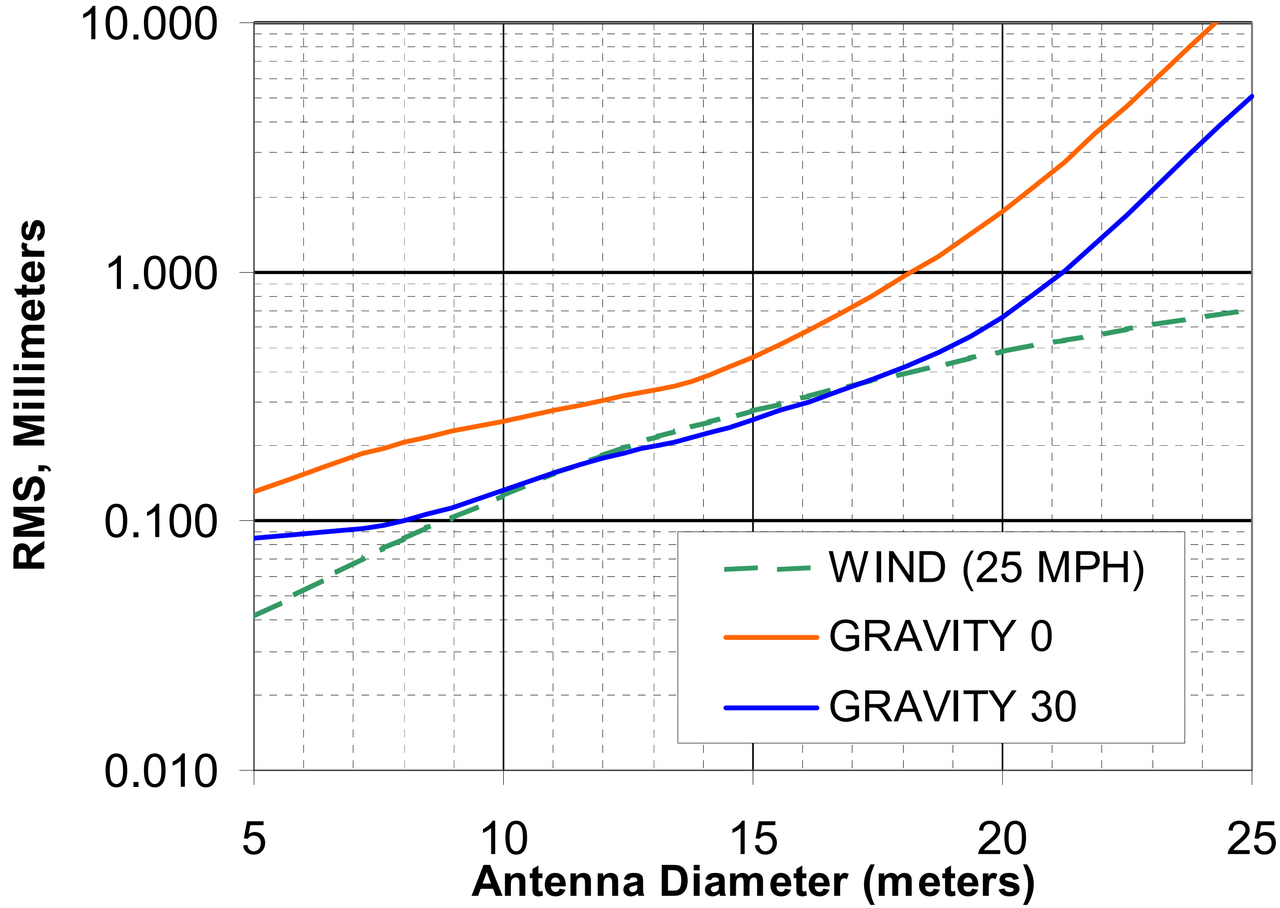
JPL has performed a structural analysis of 5m and 8m hydroformed reflectors manufactured by www.andersenanc.com and has found that the wind and gravitational distortions would allow operation at frequencies as high as 100 GHz.

Example	Antenna Diameter	Cost per Antenna	Cost per m^2	Cost per km^2
New 70m DSN antenna	70m	$100M	$40.8K	$40.8B
25m VLBA antenna	25m	$3M	$9.6K	$9.6B
6m ATA antenna	6m	$30K	$1.7K	$1.7B
Target SKA cost	10m	$30K	$600	$0.6B
Hydroformed DBSTV antenna	4m	$2.8K	$350	$0.35B
Aluminum, 3mm thick sheet	Any	NA	$30	$.03B





RMS Deformation Due to Wind and Gravity as a Function of Antenna Diameter for Hydroformed Shell of 3mm Thickness



Current DSN and SKA Antenna Requirements

Reflector Type – 12m offset Gregorian

Surface Accuracy – 0.2mm rms deviation from best fit caused by gravity, wind upto 15mph, an temperature of-–10 to +55C

Pointing Accuracy - .011^{o} or 0.7' after correction table in 15mph wind

Phase Center Stability – Shall move < 1mm due to 15mph wind or sun/shade condition.

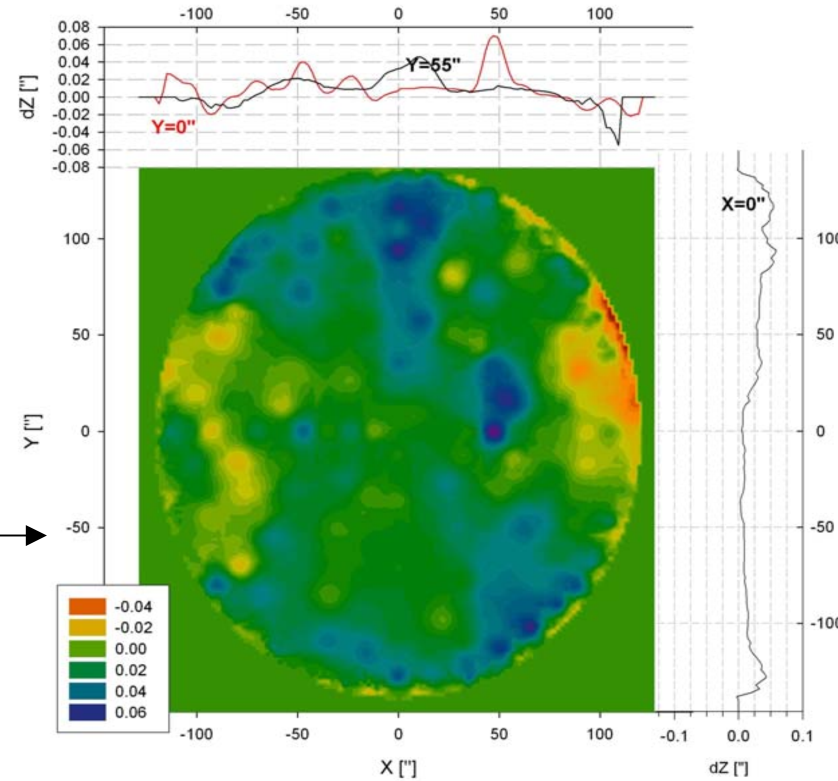
Survival – Drive to stow in 50 mph wind and survive at stow in 100 mph wind.

Receiver Mounting – 90 kg at Gregorian focus and 90 kg at prime focus including 2.4m subreflector.

6m Hydroformed ATA Antenna at Anderson Plant, May, 2002

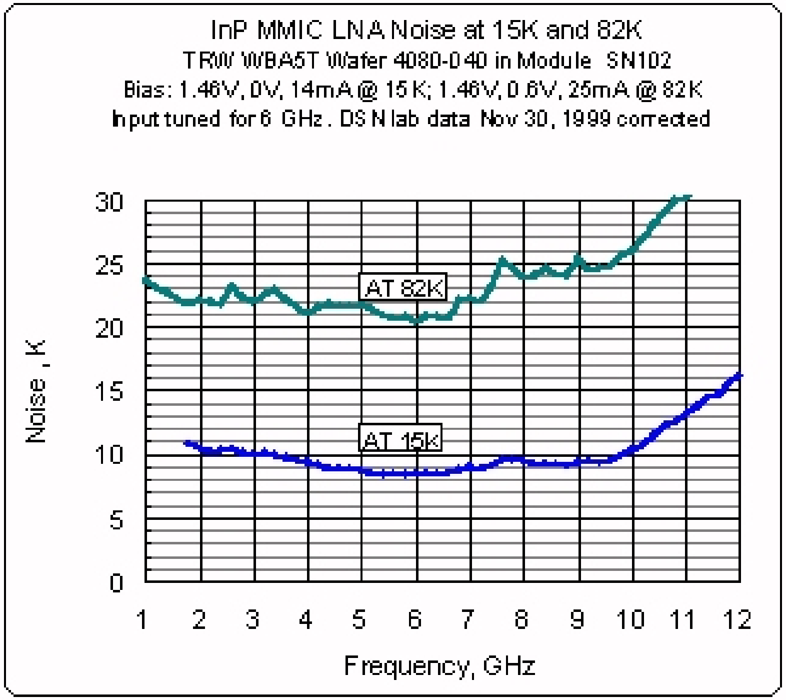
- RMS deviation is 0.68mm which is sufficient for 11 GHz ATA operation.
- Mold will be further machined with a goal of 0.20mm for JPL/Caltech 40 GHz antenna

Error map of surface →



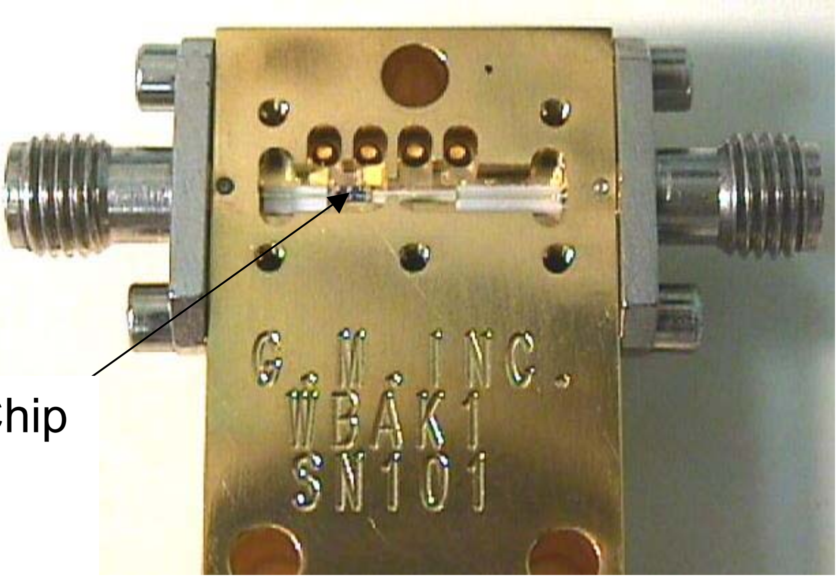
Low-Noise Cryogenic Amplifiers for Arrays

- JPL and Caltech are developing cryogenic LNA's using InP MMIC devices processed at TRW and HRL and funded by NASA and the SETI Institute.
- Thrust is to very wideband LNA's and operation at higher cryogenic temperatures to reduce cooling costs. An example is shown below
- A record noise temperature of 2K averaged over the 4 to 8 GHz band was recently measured in an LNA designed at Chalmers University (Sweden) using TRW HEMT transistors supplied by JPL.



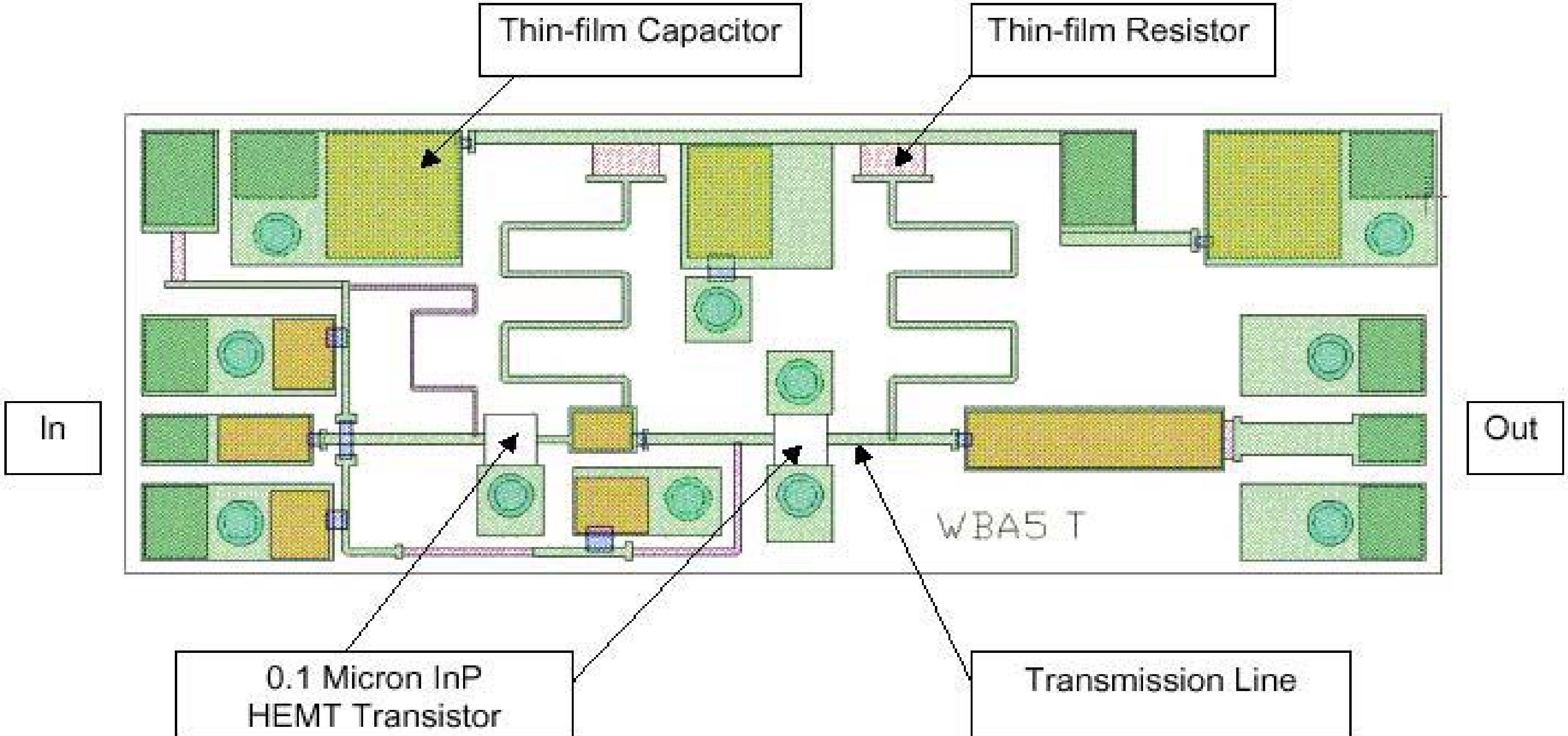
MMIC Chip

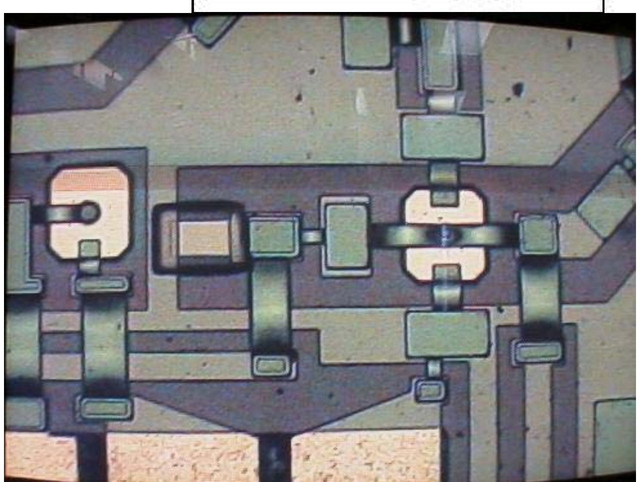
LNA



Monolithic Integrated Circuit Very Low Noise 0.5 to 11 GHz Amplifier

Chip Size – 2mm x 0.74mm x 0.1mm, Material – Indium Phosphide



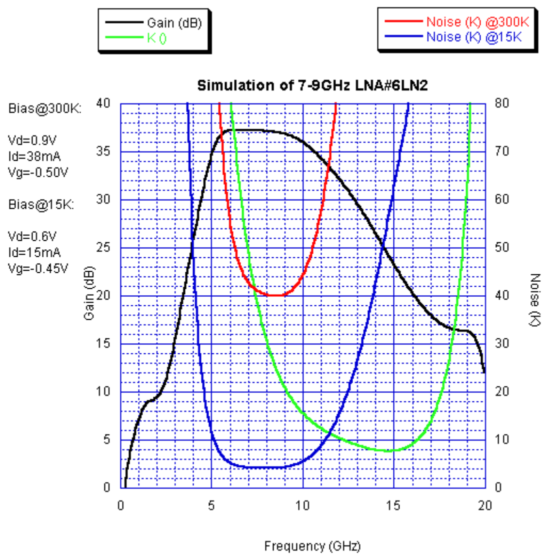


Photograph of portion of MMIC,

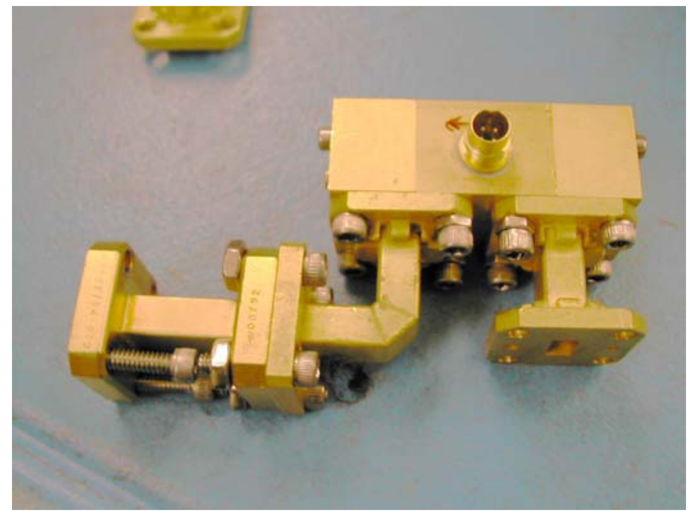
Metal strips approximately 20um wide

Cryogenic Low Noise Amplifiers for the DSN Array

X-Band LNA Designed at Caltech for Raytheon MHEMT Process



Ka-Band LNA Under Test at UCSB



Example of Multi-Function MMIC Module - Length 30mm

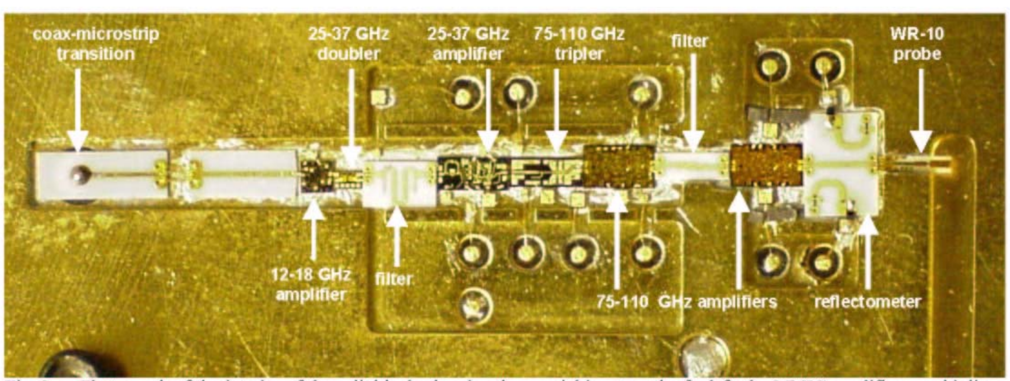


Fig. 3 Photograph of the interior of the split block, showing the coaxial input on the far left, the MMIC amplifiers, multipliers, and

Down-converter, LO multipliers, IF amplifiers, and IF switching can all be packaged in one module

Prototype DSN Array Summary Schedule

D=Design F=Fabricate A=Assemble T=Test							
Task	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**FY07**	**FY08**
Rapid Prototype 6m Interferometer							
Design	DDDD	D					
Fabricate		FFF					
Integrate		A	AAA				
Test			T	TTTTT			
Prototype 100 x 12m Array							
Design	DDDD	DDDD	DD				
Fabricate			FF	FFFFF	FFF		
Integrate				AA	AAAA	AA	
Test						TTTTT	TTTTT
Funding Requirements	**$1.2M**	**$5.8M**	**$10.9M**	**$22.0M**	**$21.9M**	**$11.1M**	**$3.1M**
Total	**$76.0M**						

Detailed Prototype Array Schedule and Milestones

P=Procure A=Assemble T=Test

WBS		FY02	FY03	FY04	FY05	FY06	FY07
1	**System Development**						
1.1	Requirements, Configuration, & Calibrate	DDDDDDDDDDDDDDD11					
1.2	Test Interferometer	DDDDDDDDDDDDFFFFFFAAAAAAAAAA12TTTTTTTTTT					
1.3	Design and Test	DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD13PPPPFFFFFFFFFFFFFAAAAAAA14TTTTTTT15					
2	**Site Development**						
2.1	Site Selection Study and Negotiations	DDDDDDDDDDD21PPPPPPPPP22					
2.2	Site Civil Work		DDDDDDDDDDDDDDDDDDDD23PPPPPFFFFFF24FFFFFFFFF				
3	**Antenna Element**						
3.1	6m Reflector and Mount	DDDDDDDDDD31PPPFFF32AAAA33TT					
3.2	12m Near-Site Factory		DDDDDDDD34PPPPPPFFFFFFF35				
3.3	12m Reflector and Mount		DDDDDDDDDDDD36PPPPFFFFFFFFFFF37AAAAATT38AAAAAAAAA39				
4	**Receivers**						
4.1	8/32/38 GHz 6m Feed	DDDDDDDDD41PPFFFF42TT43TT					
4.2	8/32/38 GHz 12m Feed			DDDDD44PPFFFFFFFFTT45TT			
4.3	8/32/38 GHz LNA	DDDDDDDDD46FFFFFFF47AA		DDDDPPPFFFFFFFF48ATTATATAAAAA49			
4.4	Cryocooler and Dewar		DDDDFFFTTT4AAATTT4B		DDDDPPPFFF4CAAATAAAAAAAA4D		
4.5	RF Analog Processing		DDDDFFFTTT4ETT	DDDDDD4FPPFFFFFFTTAAAAAAAAAAAAA			
5	**Data Transmission**						
5.1	Subsystem Design		DDDDPPAATT51DDDDDDDD52				
5.2	RF/Photonic Transceivers				PPPPFFFFFF	53AAAAAAA54	
5.3	Fiber Installation				DDDDDDPPP	55AAAAAAA56	
5.4	Remote Station Study	DD	DDDD				DDDDDDDDD
6	**Signal Processing**						
6.1	Processing Design and Coding	DDDDDDDDDDDDDDDDDD61FFFFFFFFFF62AAAAAAAAAA63TTTTTTTTTTTTTTT64					
6.2	Beam Former		DDDDDDDDDDDDDDDDDDD65FFFFFFFFFF66AAAAATTTT67				
6.3	Correlator		DDDDDDDDDDDDDDDDDDD68FFFFFFFFFF69AAAAATTTT6A				
7	**Monitor and Control**						
7.1	Interferometer Mon and Control		DDDFFFFAAATT71				
7.2	Array Monitor and Control			DDDDDDDD72FFFFFFFFFFFF73TTTT74			
7.3	Operation Interface				DDDDDDDD75	FFFFFTTTT76	
8	**Project Management**						
8.1	Staffing, Schedule, and Reporting	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX					
8.2	Cost Estimation and Control	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX					
8.3	Spectrum Management		XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX				

Prototype Array Milestones Through 2003

WBS	Milestone	Name	Date	Event
3.1	31	6m Antenna Designed	Oct-02	Complete design of backup structure and mount for precision 40 GHz version of 6m ATA antenna.
4.1	41	6m Feed Design	Oct-02	8.4 and 32-38 GHz feed design complete.
4.3	46	8 and 32 GHz LNA Design	Oct-02	8 and 32-38 GHz MMIC LNA's designed and tested
2.1	21	Site Selected	Jan-03	Preliminary Site Review
1.,1	11	Requirements Freeze	May-03	Changes after this date may have cost impact.
4.1	42	6m Feed Fabricated	Jul-03	Machining at JPL or outside shop with attention to finding future low cost quality fabricator.
3,1	32	6m Antenna Fabricated	Aug-03	Three 6m antennas including mounts fabricated.
4.3	47	8 and 32 GHz LNA Tested	Aug-03	LNA's packaged, tested, and ready for integration with feed and cryogenics.
6.1	61	Algorithm Design Complete	Sep-03	Algorithms for array calibration and beam forming complete and documented.
4.4	4A	Cryocooler Tested	Oct-03	Cryocooler including dewar for 6m tests ready for integration with feed and LNA.
4.5	4E	RF Analog Design for 6m	Oct-03	Tested RF analog system for 6m interferometer complete.
5.1	51	Interferometer Transmission	Oct-03	Design and implementation complete for interferometer data transmission system
4.1	43	6m Feed Tested	Oct-03	Patterns tested and computation of Aeff/Tsys. Ready for incorporation in cryogenics dewar.
7.1	71	Interferometer Mon & Control	Dec-03	Interferometer pointing control, delay control, and simple data processing functional.

Cost by Subsystem, FY02-04 and Total FY02-08

WBS		FY02			FY03			FY04			TOTAL WBS		
		FTE	MatK$	TotK$	FTE	MatK$	TotK$	FTE	MatK$	TotK$	FTE	MatK$	TotK$
1	**System Development**												
1.1	Requirements, Configuration, & Ca	1.0		**210**	1.5		**328**	1.5		**341**	11.0	0	**2648**
1.2	Test Interferometer	0.3		**53**	0.5		**109**	0.5		**114**	2.3	0	**511**
1.3	Design and Test	0.3		**53**	2.0		**437**	2.0		**454**	12.3	1200	**4150**
2	**Site Development**												
2.1	Site Selection Study and Negotiati	0.8	100	**258**	1.0	100	**318**			**0**	1.8	200	**576**
2.2	Site Civil Work			**0**	1.0	150	**368**	1.0	400	**627**	4.0	6550	**7477**
3	**Antenna Element**												
3.1	6m Reflector and Mount	1.0		**210**	1.0	200	**418**	1.0	100	**327**	3.0	300	**956**
3.2	12m Near-Site Factory			**0**	0.5		**109**	1.0	2000	**2227**	1.5	6000	**6336**
3.3	12m Reflector and Mount			**0**	0.5	200	**309**	1.0	300	**527**	4.5	18500	**19574**
4	**Receivers**												
4.1	8/32/38 GHz 6m Feed	0.5		**105**	0.5	40	**149**			**0**	1.0	40	**254**
4.2	8/32/38 GHz 12m Feed			**0**			**0**	0.5	50	**164**	1.0	350	**582**
4.3	8/32/38 GHz LNA	0.5		**105**	1.0	200	**418**	1.0	250	**477**	6.0	1100	**2521**
4.4	Cryocooler and Dewar			**0**	0.5	80	**189**	1.0	50	**277**	7.0	2130	**3818**
4.5	RF Analog Processing			**0**	2.0	40	**477**	2.0	200	**654**	10.0	1490	**3866**
5	**Data Transmission**												
5.1	Subsystem Design			**0**	1.0	20	**238**	1.0	50	**277**	2.0	70	**516**
5.2	RF/Photonic Transceivers			**0**			**0**	1.0	50	**277**	4.0	1450	**2415**
5.3	Fiber Installation			**0**			**0**	0.5		**114**	4.0	850	**1809**
5.4	Remote Station Study	0.1		**21**	0.5	20	**129**	0.5	20	**134**	3.1	210	**955**
6	**Signal Processing**												
6.1	Processing Design and Coding	0.5		**105**	1.0		**218**	1.0		**227**	2.5	0	**551**
6.2	Beam Former			**0**	1.0	50	**268**	3.0	200	**881**	11.5	1150	**3884**
6.3	Correlator			**0**	1.0	50	**268**	3.0	200	**881**	11.5	850	**3584**
7	**Monitor and Control**			**0**			**0**			**0**			
7.1	Interferometer Mon and Control			**0**	1.5	50	**378**	1.0	20	**247**	2.5	70	**625**
7.2	Array Monitor and Control			**0**			**0**	3.0	100	**781**	12.0	800	**3704**
7.3	Operation Interface			**0**			**0**			**0**	3.5	0	**885**
8	**Project Management**												
8.1	Staffing, Schedule, and Reportin	0.3		**53**	2.0	50	**487**	2.0	100	**554**	9.3	400	**2563**
8.2	Cost Estimation and Control	0.3		**53**	0.5		**109**	1.0		**227**	3.8	0	**871**
8.3	Spectrum Management			**0**	0.2		**44**	0.5		**114**	1.7	0	**398**
	Total FTE Personnel	**5.4**	**100**	**1224**	**20.7**	**1250**	**5771**	**30.0**	**4090**	**10904**	**136.6**	**43710**	**76028**

Array Personnel Plan FY03-08

($210K per FTE in FY02, Escalated 1.04 per year, Estimates of Jan 2002)

Array Personel Chart			FY02 Cost FTE	210	Escalation		1.04		
	Position	**FY03 Person**	**FY03**	**FY04**	**FY05**	**FY06**	**FY07**	**FY08**	**Total**
1	Program Manager		1	1	1	1	1		5
2	Business Manager		1	1	1	1			4
3	Administrative Ass't		0.5	1	1	1			3.5
4	Project Scientist A		1	1	1	1	1	1	6
5	Project Scientist B		1	1	1	1	1	1	6
6	Project Engineer		1	1	1	1	1	1	6
7	System Engineer		1	1	1	1	1	1	6
8	Site Engineer		1	1	1	1			4
9	Antenna Engineer A		1	1	1	1	1		5
10	Antenna Engineer B		1	1					2
11	Antenna Control Eng			1	1				2
12	Feed Engineer		0.5	1	1	1			3.5
13	Cryocooler Engineer		0.5	1	1				2.5
14	Front-End Engineer		1	1	1	1	1	1	6
15	RF Analog Engineer		1	1	1	1	1		5
16	LO Engineer		1	1	1	1			4
17	RF Test Engineer				1	1	1		3
18	Fiber Transmission Eng		1	1	1	1	1		5
19	Fiber Technician					1	1		2
20	Photonic Eng			1	1	1			3
21	Remote Link Eng		0.5	0.5	0.5	0.5	0.5	0.5	3
22	Signal Processing Eng		1	1	1	1	1	1	6
23	Beam Former Eng A		1	1	1	1	1		5
24	Beam Former Eng B			1	1	1			3
25	Beam Former Programmer			1	1	1	1	1	5
26	Correlator Eng A		1	1	1	1	1		5
27	Correlator Eng B			1	1	1			3
28	Correlator Programmer			1	1	1	1	1	5
29	Mon & Cont Eng A		1	1	1	1	1	1	6
30	Mon & Cont Eng B		0.5	1	1	1	1		4.5
31	Mon & Cont Programmer			1	1	1	1		4
32	Operation Interface Eng					1	1	1	3
		Total FTE	19.5	28.5	28.5	28.5	20.5	10.5	136
		FY Labor Cost, $K	$4,259	$6,473	$6,732	$7,002	$5,238	$2,790	$32,494

Basis of Cost Estimate for Items Above $3.8M

WBS	Task	Amount K$	JPL FTE	Basis of Estimate
3.3	12m Reflector and Mour	$19,574	4.5	Cost per 12m antenna is $256K including reflectors, drives, foundation, installation and the nea factory (WBS 3.2). This is close to a 0.14D^3 curve which fits ATA 6m at $32K and VLBA 25m $2.2M, Material cost for 12m x 12m x .005m aluminum sheet is $6.5K and 40 hours labor at $ should be sufficient to form the reflector. Allowing $30K for backup structure, $50K for drives,$20K for foundation, and $24K for 400 hours for assembly and installation gives a total $133K which is well below the $194K estimate not including the non-recurring factory cost.
2.2	Site Civil Work	$7,477	4.0	This includes A&E design, grading, power, foundations, and a 500 m^2 array maintenance facilit a 0.6 x 0.6 km site (60m spacing of 100 12m antennas).
3.2	12m Near-Site Factory	$6,336	1.5	This is based upon $5M estimate given by John Andersen (August 2001) which includes 12m tooling (mold) of $3M, hydroforming equipment at $1M, and a 20m x 50m metal building enclos at $1M.
1.3	Prototype Array System	$4,150	12.3	This include system design of the array, monitoring of subsystem specifications and test result and testing of the array as it becomes functional. Two FTE are provided each year for Project Scientist and Project Engineer functions, The array testing is supported by contract for four operators in years FY06-08.
6.2	Beam Former	$3,884	11.5	Using the SKA cost equation for processing with 8 100 MHz beams gives a component cost o $750K. The 8.5 FTE provides for design, assembly , and testing.
4.5	RF Analog Processing	$3,866	10.0	Includes signal switching, level control, downconversion, IF amplification, and local oscillator distribution at antenna and control center. Component cost is estimate in is $6K per antenna pl $4K for factory integration and test. The FTE are for design, prototyping, installation, and syst test.
4.4	Cryocooler and Dewar	$3,818	7.0	Per antenna includes 15K cooler at $8K, dewar machining at $2K, vacuum pump at $1K, integr with feed and LNA's at $3K, and antenna installation and test at $3K; total $17K x 100 = $1.7M JPL FTE's for design, subcontract management, and non-recurring prototype costs make up t balance.

Goals for a Caltech/JPL SKA/DSN Development Program

System Design

- Design interfaces to user and science community
- Find optimum antenna element size and array configuration

Antenna Manufacture

- Develop manufacturing technology to reach \$600/m^2 cost target
- Monitor ATA 350x6m manufacture
- Construct small antenna prototypes to verify cost and performance

Transmitter Design

- Design, fabricate, and test solid state 7 and 33 GHz HPA's (100W, 5W)
- Develop diplexer and exciter
- Develop geosynchronous satellite monitor receiver for transmitter phasing

Receiver Development

- Develop low cost MMIC LNA's , feed, and cryogenics; target \$10K

Connectivity

- Develop satellite relay LO distribution and fiber-optic signal transmission

Signal Processing

- Design and prototype digital beam former and correlator

Array Technology Work in Progress at Caltech and JPL

May, 2002

At Caltech

• **ATA Low Noise Receiver** – Niklas Wadefalk works on MMIC design and prototype construction for 0.5 to 11 GHz cryogenic low noise receiver.

• **Caltech 6m Antenna** – Contracted to Andersen to improve surface of ATA reflectors to allow 40 GHz operation.

At JPL

•**DSN Array System Design** – Durga Bagri, Mick Connally, Dayton Jones work on system requirements and block diagram design

•**Antenna Pedestal Design** – Roger Schultz is designing a pedestal and drive system for the Andersen 6m reflector.

•**8/32 GHz Feed Design** – Dan Hoppe is designing a concentric dual frequency feed.

•**8.4 and 32 GHz LNA Design** – Sandy Weinreb is working with Jose Fernandez, Steve Montinez, and UCSB on assembly and testing of MMIC LNA’s

Students Participating in Array Development at Caltech

2002

Student	School	Project
Summer Undergraduate Research Students, 2002		
Eric Anderson	Caltech	Modeling of hydroformed reflector fabrication
Joe Barden	UCSB	Precision timing distribution by commercial satellite
Glenn Jones	Caltech	Cryogenic transistor testing
Anton Aboukhalil	McGill	Design of antenna servo system
Muhammad Ahmed	Georgia Tech	Digital data processing for Caltech/JPL interferometer.
Graduate Students		
Matthew Morgan	Caltech	MMIC design and test, 32 GHz LNA
Robert Hu	U. Michigan	Cryogenic noise parameters, 8-20 GHz LNA
Patrick Cesarano	Caltech	New student starting July, 2002

Caltech Array Technology Development Center

Concept

A center on the Caltech campus for development of technology for both radio astronomy and space communications. Financial support from a $10M endowment from Caltech gift funds is proposed.

Summary of Benefits

1)The center will spear-head and jump-start a next-generation radio astronomy project, the SKA, with enormous science impact.

2)The center provides stimulation, oversight, and future personnel for a JPL DSN array initiative which involves billions of dollars and decades of use.

3) The center provides a leadership role for Caltech in the SKA. It is a prudent investment in the future of radio astronomy at Caltech.

4)The center stimulates and benefits from departmental collaboration.

Rationale for Proposed Caltech Array Development Center

Caltech led the nation into radio astronomy interferometry and arrays in the 1960's and it's alumni still guide most of the ongoing efforts at the VLA, VLBA, and ALMA radio arrays. Because of its outstanding astrophysics program at many wavelengths, its experience with the Owens Valley Radio Observatory, and the association with JPL it is appropriate for Caltech to play a strong leadership role in future radio arrays.

Technology Areas of Interest

1) Design of precision reflector and drive system structures which can be reproduced at low cost.

2) Development of very wideband low noise receivers including long life cryogenic systems

3) Systems for one picosecond time synchronization at antennas which may be over 1000 km apart

4) Affordable gigabit data transmission systems

5) Hardware and software for processing of the order of 10^{14} bits per second which will be received by the array.